

# EVOLUTION OF OPTICALLY FAINT AGN FROM COMBO-17 AND GEMS

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We have mapped the AGN luminosity function and its evolution between  $z = 1$  and  $z = 5$  down to apparent magnitudes of  $R < 24$ . Within the GEMS project we have analysed HST-ACS images of many AGN in the Extended Chandra Deep Field South, enabling us to assess the evolution of AGN host galaxy properties with cosmic time.

## 1. Introduction

This article is a report on recent progress in the study of optically faint Active Galactic Nuclei (AGN). Most of the content has recently been published elsewhere; on the following pages we provide a concise summary and present some of the key figures.

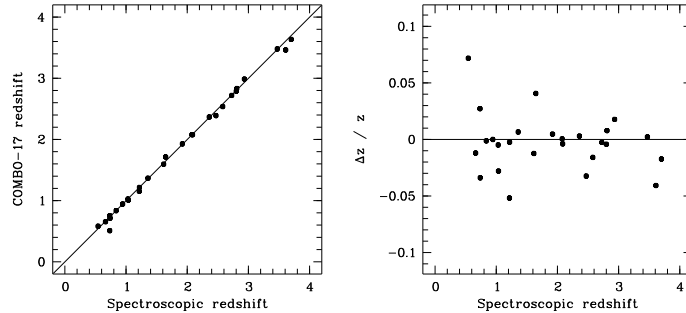


Figure 1. COMBO-17 spectrophotometric redshifts of AGN vs. spectroscopic redshifts.

## 2. The AGN luminosity function from COMBO-17

The COMBO-17 survey (Wolf et al. 2004<sup>1</sup>) uses multi-band photometry in 17 filters within  $350 \text{ nm} \lesssim \lambda_{\text{obs}} \lesssim 930 \text{ nm}$ . By matching the photometry to an extensive template library, we can simultaneously determine photometric redshifts of AGN with an accuracy of  $\sigma_z < 0.03$  (Fig. 1), and obtain spectral energy distributions. We have defined an AGN sample within  $1.2 < z < 4.8$ , which implies that even at  $z \simeq 3$ , the sample reaches below luminosities corresponding to  $M_B = -23$ , conventionally employed to distinguish between Seyfert galaxies and quasars.

We clearly detect a broad plateau-like maximum of quasar activity around  $z \simeq 2$  and map out the smooth turnover between  $z \simeq 1$  and  $z \simeq 4$ . The shape of the luminosity function is characterised by some mild curvature, but no sharp ‘break’ is present within the range of luminosities covered. Using only the COMBO-17 data, the evolving LF can be adequately described by either a pure density evolution (PDE) or a pure luminosity evolution (PLE) model. However, the absence of a strong  $L^*$ -like feature in the shape of the LF inhibits a robust distinction between these modes.

We present a robust estimate for the integrated UV luminosity generation by AGN as a function of redshift. We find that the LF continues to rise even at the lowest luminosities probed by our survey, but that the slope is sufficiently shallow that the contribution of low-luminosity AGN to the UV luminosity density is negligible. Although our sample reaches much fainter flux levels than previous data sets, our results on space densities and LF slopes are completely consistent with extrapolations from recent major surveys such as SDSS and 2QZ. Details of this analysis are published in the paper by Wolf et al. (2003<sup>2</sup>).

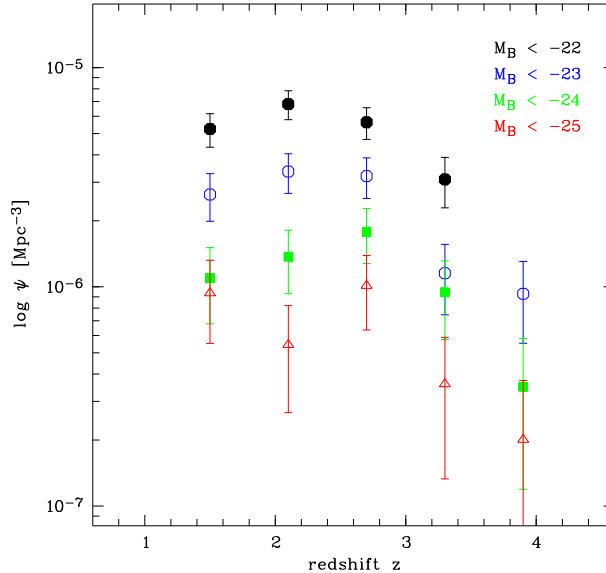


Figure 2. Space density of AGN in COMBO-17 as a function of redshift, for different low-luminosity cutoffs.

### 3. Colors and stellar masses of AGN host galaxies at intermediate redshifts from GEMS

GEMS is a two bands, F606W and F850LP, HST imaging survey of a continuous field of the ‘Extended Chandra Deep Field South’, stretching over  $28' \times 28'$  in the sky (Rix et al. 2004<sup>3</sup>). In this field, COMBO-17 provides SEDs and redshifts of  $\sim 10000$  galaxies and  $\sim 100$  AGN. We have constructed a subsample of these AGN by defining a redshift slice,  $0.5 < z < 1.1$ , where the two GEMS bands bracket the rest-frame 4000 Å break. We have detected the hosts of all these AGN in the F606W-band, recovering their fluxes, morphologies and structural parameters. A full account of this work is given by Sanchez et al. (2004<sup>4</sup>).

Morphologically, the AGN host galaxies are predominantly of early-type ( $\sim 80\%$ ). Less than  $\sim 20\%$  have structural properties characteristic of late-type galaxies. The fraction of objects with disturbed morphological appearance suggestive of ongoing galaxy interactions is also  $\sim 20\%$ . The hosts show a wide range of colors, from being as red as red sequence galaxies to colors as blue as galaxies undergoing star formation. Comparing with single stellar population models, the average stellar population would have an age of  $\sim 1$  Gyr. With  $\sim 70\%$  of the objects having  $U - V < 0.8$ ,

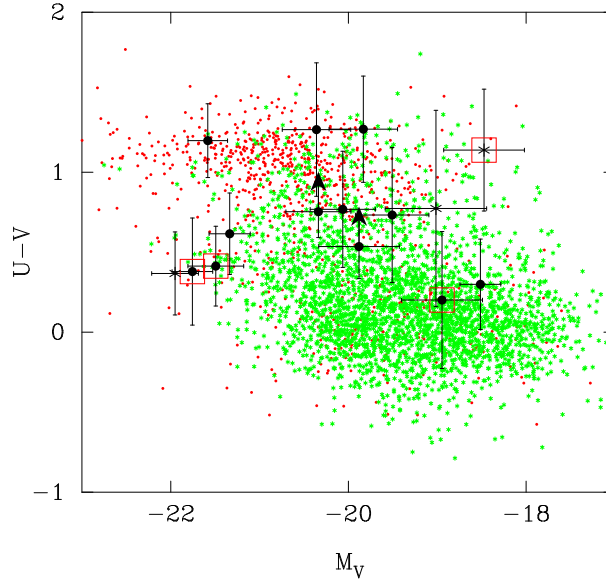


Figure 3. Colors and absolute magnitudes of AGN host galaxies from GEMS within  $0.5 < z < 1.1$ . Filled symbols denote early-type systems, open squares indicate interacting or merging objects. For comparison, we show also the corresponding distribution of inactive galaxies at the same redshift range. The red sequence for elliptical galaxies is clearly identified with  $U - V \gtrsim 0.8$ . The elliptical AGN hosts are clearly bluer, on average, than the red sequence.

the early-type AGN hosts are significantly bluer than red sequence early-type galaxies (see Fig. 3). However, their color-magnitude distribution is consistent with the distribution of *all* inactive early-type galaxies in the GEMS field when also the blue tail of these objects is taken into account.

Despite their sometimes very blue colors, the early-type AGN hosts are structurally similar to red sequence ellipticals: They follow the Kormendy relation (Fig. 4), and their absolute magnitudes ( $M_V \sim -20.2$ ), effective radii ( $r_{1/2} \sim 2$  kpc) and stellar masses ( $\sim 10^{10}$ – $10^{11} M_\odot$ ) are in the range of normal ellipticals.

#### 4. UV light in QSO host galaxies at $1.8 < z < 2.75$

We have exploited GEMS to investigate a sample of 23 AGN in the redshift range  $1.8 < z < 2.75$ , also drawn from the COMBO-17 survey. In 9 of the 23 AGN we resolve the host galaxies in both filter bands, whereas in the remaining 14 objects, any resolved components have less than 5 %

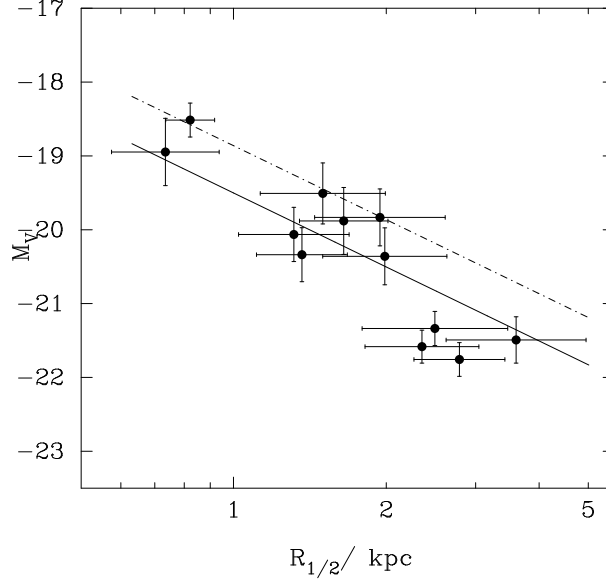


Figure 4. Host galaxy absolute magnitudes against half-light radii for the 12 early-type galaxies at  $0.5 < z < 1.1$  (filled circles). The solid line shows the luminosity-size relation for early-type red sequence galaxies at the mean redshift of our objects (Schade et al. 1997<sup>5</sup>). The dashed-dotted line shows the relation at  $z = 0$  from Kormendy (1977<sup>6</sup>).

of the nuclear flux and were considered nondetections. However, when we coadd the unresolved AGN images into a single high signal-to-noise composite image we find again an unambiguously resolved host galaxy. The recovered host galaxies have apparent magnitudes of  $23.0 < F606W < 26.0$  and  $22.5 < F850LP < 24.5$  with rest-frame UV colours in the range  $-0.2 < (F606W - F850LP)_{\text{obs}} < 2.3$ . The rest-frame absolute magnitudes at 200 nm are  $-20.0 < M_{200 \text{ nm}} < -22.2$ . The photometric properties of the composite host are consistent with the individual resolved host galaxies.

We find that the UV colors of all host galaxies are substantially bluer than expected from an old population of stars with formation redshift  $z \leq 5$ , independent of the assumed metallicities. These UV colours and luminosities range up to the values found for Lyman-break galaxies (LBGs) at  $z = 3$ . The presence of significant amounts of UV light suggest either a recent starburst, of e.g. a few per cent of the total stellar mass and 100 Myrs before observation, with mass-fraction and age strongly degenerate, or ongoing star formation. For the latter case we estimate star formation rates of typically  $\sim 6 M_{\odot} \text{ yr}^{-1}$  (uncorrected for internal dust attenuation), which again

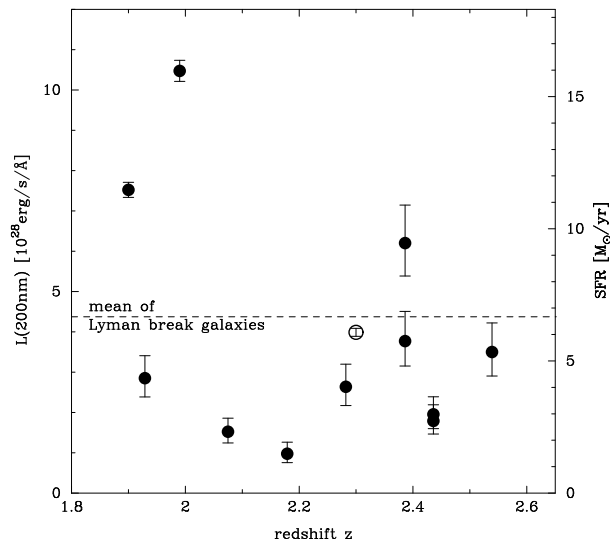


Figure 5. Rest frame 200nm luminosities, and star formation rates as derived from the F606W-band, both uncorrected for dust. The open symbol marks the SFR of the ‘stacked’ object created from the AGNs with individually unresolved host galaxies. The horizontal dashed line is the value obtained by Erb et al. (2003<sup>8</sup>) for Lyman break galaxies at  $z = 2.5$ .

lies in the range of rates implied from the UV flux of LBGs. For details see our recently submitted paper (Jahnke et al. 2004<sup>7</sup>).

## References

1. Wolf C., Meisenheimer K., Kleinheinrich M., et al., 2004, A&A, submitted, astro-ph/0403666
2. Wolf C., Wisotzki L., Borch A., Dye S., Kleinheinrich M., and Meisenheimer K., 2003, A&A, 408, 499
3. Rix, H.-W., Barden, M., Beckwith, S.V.W., et al., 2004, ApJS, in press, astro-ph/0401427
4. Sanchez S.F., Jahnke K., Wisotzki L., et al., 2004, ApJ, submitted, astro-ph/0403645
5. Schade, D., Barrientos, L. F., & Lopez-Cruz, O., 1997, ApJL, 477, L17
6. Kormendy, J., 1977, ApJ, 218, 333
7. Jahnke K., Sanchez S.-F., Wisotzki L., et al., 2004, ApJ, submitted, astro-ph/0403462
8. Erb, D.K., Shapley, A.E., Steidel, C.C., et al., 2003, ApJ 591, 101